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SCINTILLATION AND DANCING OF LASER BEAM
PROPAGATION IN MARINE ATMOSPHERE

by

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SCINTILLATION AND DANCING OF LASER BEAM PROPAGATION IN MARINE ATMOSPHERE

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Abstract: In this paper, experimental results of intensity fluctuation (scintillation) and dancing (angle-of-arrival fluctuation and isoplanatic angle) of laser beam at Dawanshan Islands are reported. The results are comparied with the data of turbulent intensity measured simulteneously. It is indicated that the turbulence in marine atmosphere of the South China Sea during late autumn and early winter is rather violent, and it's effect on laser propagation is remarkable.

I. Introduction

As early as the early sixties, the possibilities of marine applications of lasers began to be studied. By now, multiple laser engineering projects on airborne marine bathymeters and pollution measurement with lasers have been developed. Since the laser beam in these engineering projects has to penetrate the atmosphere at the sea surface, and is affected by atmospheric

turbulence, properties of laser intensity fluctuations (scintillation) and dancing (fluctuations in angle of arrival and fluctuations in isoplanatic angle) have practical significance on the design and applications of marine laser projects.

From late October to mid-November 1989, the authors conducted measurements on laser scintillation and dancing at Dawanshan Islands in the South China Sea. Moreover, turbulence intensities were observed in order to understand the atmospheric properties. The article reports the observation results on scintillation and dancing with an analysis based on present-day theory.

II. General Situation of Measurements

The experiments were conducted at Dawanshan Island and Xiaowanshan Island in the South China Sea. Two transmission light paths were selected, with distances of 1800m and 500m, respectively. Our base was established at the west end of Wanshan Village on Dawanshan Island. When carrying out long-distance experiments, a reflective mirror set up on a rock in the southeast part of Xiaowashan Island reflected the laser beams. While conducting short-distance experiments, the laser device (direct optical path) or the reflective mirror (reflective light path) were set up on a rock across the bay from the other site. The light path was about 12m above the sea surface.

In the scintillation and dancing experiments, an He-Ne laser (λ=0.6328µm) was used. Fig. 1 shows the experimental setup.

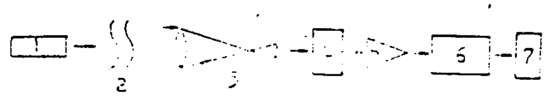

Fig. 1. Brief experimental setup
LEGEND: 1 - He-Ne laser 2 - atmosphere 3 - receiving telescope 4 - detector 5 - amplification 6 - data collector 7 - computer

Without passing through a telescope, the laser beam directly illuminated (or reflected, after passing a flat reflective mirror) onto a refractive or an OD200mm receiving telescope; electrical signals were converted with a detector. After amplification, the signal was fed to a microcomputer for processing via a data collector. During scintillation measurements, an optoelectronic multiplier was used in the detector. During the dancing measurements, a four-quadrant silicon optoelectronic diode was used. The nonlinear problems of the detector were corrected with a computer. The minimum angle of resolution of the system was 0.78μradian; the overall measurement error was approximately 5%. The measurement error is directly related to the nonlinearity and reception of the detector, mechanical stabilization of the emitting system, and the performance of the multichannel data amplifier.

III. Experimental Results

1. Scintillation

From November 7 to 9, scintillation of the He-Ne laser between Dawanshan and Xiaowanshan islands was measured with the reflecting optical path. Overall, 160 data sets were measured.

The data processing method is the same as in [1]. Fig. 2 gives the time-dependent variation of the logarithmic intensity variance $\sigma_{lnI}2$ on November 8, from 1100 hours to 2300 hours. The situations indicated in the figure are very typical. On the morning of that day, there were thin clouds at high altitudes. At about 1230 hours, the weather turned cloudy. After 1600 hours, the weather turned sunny, until sunset. The scintillation intensity apparently varied with the weather conditions. At night, $\sigma_{lnI}2$ gradually weakened, but was still greater than on cloudy days. This variation is mainly due to insolation that we had measured several times previously. Undoubtedly, this matches the general rule.

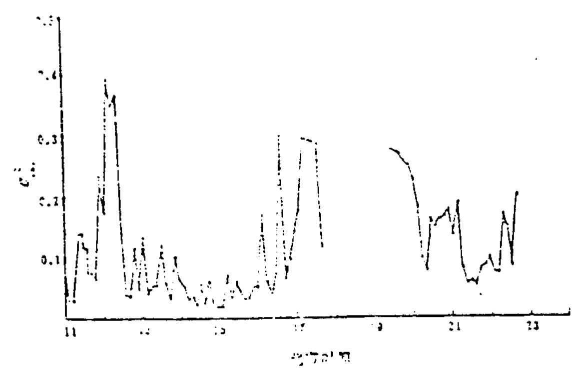

Fig. 2. Diurnal variation of scintillation (at Dawanshan on November 8, 1989)

Theoretically, the scintillation intensity (spherical surface wave) of the reflective optical path is [2]

$$\sigma_{lnI}^2 = 2 \times 0.496 C_n^2 k^{7/6} (2L)^{11/6} \tag{1}$$

In the equation, C_n2 is the turbulence intensity, $k=2\pi/\lambda$. λ is the wavelength of the laser; L is the transmission distance. On

the right-hand side of the equation, the factor 2 is the number of applications of the reflective optical path. Now λ=0.6328λ and L=1.8km. Thus, we can calculate that the mean turbulence intensity on the optical path is

$$C_n^2 = 2.092 \times 10^{-15} \sigma_{lnI}^2 \qquad (2)$$

The foregoing equation applies to the case of a pointwise receiving aperture. In actual application, an OD200mm receiving aperture was used. Hence, the aperture-smoothing factor is required for revision. From the theoretical curve, we obtain θ approximately equal to 0.02. Therefore,

$$C_n^2 = 1.05 \times 10^{-13} \sigma_{lnI}^2 \qquad (3)$$

The measured $\sigma_{lnI}2$ is 0.7 at the maximum, and 0.02 at the minimum. Thus, we know that the variation range of C_n2 is between 2x10-15 and 7x10-14m$^{-2/3}$. The result is quite consistent with the result of temperature fluctuation measurements (in the latter case, the maximum is 9x10-14m$^{-2/3}$, and the minimum is 1.7x10-15m$^{-2/3}$). As for comparison point-by-point, since the turbulence detector was set up at a site that was not in the light path, during the measurements, synchronization was not carried out, therefore, it was unable to be proceeded with. However, as the average, the daylight average for scintillation intensity is 0.27 (1100 to 1500 hours at November 9). The converted C_n2 is 2.7x10-14m$^{-2/3}$, which is smaller than the mean daylight result for temperature fluctuation measurements at 5x10-14m$^{-2/3}$. This can be understood because the light path was

almost entirely over the empty sea surface, but the turbulence detector was set up on a slope greatly affected by terrain, so that more intensive turbulence was measured.

2. Dancing

Light-beam dancing was measured by using a four-quadrant optoelectronic diode system, which is detailed in reference [3]. At Wanshan, the authors measured the dancing of direct light path by using 5m as the optical path, acquiring a total of 38 data sets (refer to Table 1). In the system, we also can measure the fluctuations in light intensity, to derive the isoplanatic angle with a theoretical formula. The theoretical relationships of fluctuations in the angle of arrival and in the isoplanatic angle are, respectively:

$$\sigma_a^2 = 2.912 C_n^2 L D^{-1/3} \tag{4}$$

$$\theta_0 = 0.9676 \left[\log(1 + \sigma_s^2 / S^2) \right] \tag{5}$$

In the equations, D is the aperture of the receiving telescope; $\sigma_a 2$ is the variation of signal fluctuation; S is the average value of the signal. Thus, we know that the average refractivity structure constants $C_n 2(\alpha)$ and $C_n 2(\theta_0)$ are:

$$C_n^2(\alpha) = 1.07 \times 10^{-[illegible]} \sigma_a^2 \tag{6}$$

$$C_n^2(\theta_0) = 1.48 \times 10^{-[illegible]} \theta_0^{-[illegible]} \tag{7}$$

With respect to Eq. (7), the aperture-smoothing factor (θ_0=0.1) was calculated.

TABLE 1. Measurement Values of Standard Difference of Angle of Arrival and Isoplanatic Angle

a 日期 b	时间	σ_a	$C_n^2(a)$	θ_0	$C_n^2(\theta_0)$
11/09/89	20:08	7.54E-06	6.100177E-14	9.11E-06	3.71692E-14
11/09/89	20:28	3.09E-06	1.024511E-14	0.0000184	1.151729E-14
11/09/89	20:38	3.54E-06	1.344641E-14	0.0000139	1.838044E-14
11/09/89	20:48	3.32E-06	1.182704E-14	0.0000141	1.794794E-14
11/09/89	21:05	2.91E-06	9.086271E-15	0.0000159	1.469099E-14
11/09/89	21:17	3.31E-06	1.17559E-14	0.0000253	6.774007E-15
11/09/89	21:28	4.73E-06	2.400612E-14	7.74E-06	4.876913E-14
11/09/89	21:39	2.72E-06	7.938483E-15	0.0000277	5.824342E-15
11/10/89	09:45	0.000003	9.657001E-15	0.0000455	2.546992E-15
11/10/89	09:58	4.69E-06	2.360182E-14	0.000018	1.1947E-14
11/10/89	10:10	4.52E-06	2.192182E-14	0.0000134	1.953767E-14
11/10/89	10:28	3.89E-06	1.623674E-14	0.000018	1.1947E-14
11/10/89	10:38	5.24E-06	2.946201E-14	0.0000232	7.826484E-15
11/10/89	10:48	4.21E-06	1.901796E-14	0.0000235	7.660672E-15
11/10/89	11:11	3.95E-06	1.674148E-14	0.0000261	6.43151E-15
11/10/89	11:36	3.46E-06	1.284553E-14	0.0000196	1.036621E-14
11/10/89	11:48	5.08E-06	2.769027E-14	0.0000185	1.141372E-14
11/10/89	11:58	3.88E-06	1.615337E-14	0.0000151	1.601098E-14
11/10/89	12:15	4.32E-06	2.002475E-14	0.0000137	1.882979E-14
11/10/89	12:25	8.35E-06	7.481224E-14	5.65E-06	8.240728E-14
11/10/89	12:38	4.38E-06	2.058486E-14	0.0000176	1.240297E-14
11/10/89	12:50	3.83E-06	1.573973E-14	0.0000159	1.469099E-14
11/10/89	13:02	3.83E-06	1.573973E-14	0.000037	3.595097E-15
11/10/89	14:41	3.15E-06	1.064684E-14	0.0000439	2.703581E-15
11/10/89	14:51	0.0000034	1.240388E-14	0.0000353	3.888266E-15
11/10/89	15:02	2.43E-06	6.335958E-15	0.0000484	2.297762E-15
11/10/89	15:13	0.0000024	6.18048E-15	0.000044	2.693349E-15
11/10/89	15:25	5.73E-06	3.52297E-14	0.0000135	1.929703E-14
11/10/89	15:35	3.15E-06	1.064684E-14	0.0000269	6.115888E-15
11/10/89	15:46	3.37E-06	1.218596E-14	0.0000251	6.864213E-15
11/10/89	16:02	4.78E-06	2.451633E-14	0.0000173	1.276348E-14
11/10/89	16:28	2.28E-06	5.577883E-15	0.0000381	3.423781E-15
11/10/89	16:45	0.0000064	4.395008E-14	0.0000118	2.414963E-14
11/10/89	16:51	0.0000067	4.816697E-14	7.27E-06	5.413634E-14
11/10/89	17:08	4.62E-06	2.290254E-14	0.000016	1.453829E-14
11/10/89	17:19	2.46E-06	6.493367E-15	0.0000371	3.57896E-15
11/10/89	17:28	6.47E-06	4.491675E-14	5.94E-06	7.581168E-14
11/10/89	17:42	3.56E-06	1.359877E-14	9.78E-06	3.30229E-14

KEY: a - date b - time

From Table 1, the maximum dancing angle of the mean square root of the light beam is 8.4μradians; the minimum measured was 2.3μradians. The corresponding value of C_n2 (a) is between 5.6 x 10-15 and 7.5 x 10-14m$^{-2/3}$. As for scintillation, its value

can be compared with the measurement results of temperature fluctuations. As for the reason why no smaller value than 2μradians were obtained, it is possibly related to system error. The isoplanatic angle θ_0 varies between 5.7 and 18μradians. The variation range for the converted $C_n2(\theta)$ is between $2.3x10^{-15}$ and $8.2x10\text{-}14m^{-2/3}$. These values are relatively closer to the measured results of temperature fluctuations.

σ_a and θ_0 were obtained from measurement with the same sign. The average equivalent turbulence intensity was quite consistent, at 2.09 x10-14m and $1.75x10\text{-}14m^{-2/3}$. However, the correlation coefficient of the two is about 0.8. Theoretically, the fluctuation of the oscillation amplitude should be related to the phase fluctuation. The fact of not entirely correlating is possibly traceable to some problems in measurements. As indicted from some theoretical analysis, the measurement of the isoplanatic angle should apply an OD110mm receiver aperture about but we used the OD200mm receiving telescope. Besides if there are other regions, such as theoretical problems, this point will be in our latter work.

IV. Preliminary Conclusions

As indicated by the measurement results of scintillation, the atmospheric turbulence was still quite high in the sea territory of Dawanshan Islands in the late fall and early winter. If based on the relationship $Z^{-4/3}$ between turbulence intensity and altitude to be derived to a height of 1.5m above the sea

surface, then the turbulence intensity is approximately between 3x10-14 and 1x10-12m$^{-2/3}$. These values are fundamentally in the range between intermediate to high turbulence in the atmosphere on the ground surface. The reason is apparently related to local climate. Since its latitude is relatively low (21°56'min N. Lat.), insolation is still intensive even in the late fall and the early winter. The average temperature may be between 22 and 27°C. The temperature at night was still not low; temperatures at 2100 hours corresponded to the temperature at 0900 hours. Our measurement results clearly indicate this property. Therefore, the above-mentioned features should be noted when designing and applying laser engineering projects for marine investigations.

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